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APPLICATION FOR UNITED STATES LETTERS PATENT

**METHOD AND SYSTEM OF TRANSFERRING
DATA GATHERED BY DOWNHOLE DEVICES
TO SURFACE DEVICES**

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CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] None.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable.

BACKGROUND OF THE INVENTION

Field of the Invention

[0003] Embodiments of the invention are directed to transferring of data gathered by downhole devices to surface devices. More particularly, the various embodiments are directed to a non-volatile memory device to which data is stored downhole, and wherein the non-volatile memory may be decoupled from the downhole device and coupled to a surface computer to transfer data gathered downhole.

Background of the Invention

[0004] Wireline logging is a technique whereby a probe (or sonde) may be lowered into a borehole and used to gather information about the formation surrounding the borehole and/or the borehole itself. Information gathered may be sent to the surface by way of an armored multi-conductor cable, which cable therefore acts not only to suspend the sonde within the borehole, but also as a communication path between the sensors and surface devices. However, wireline logging has fallen into disfavor when associated with the drilling process because of the need to remove (or trip) the drill string before the sonde may be placed within the borehole. For this reason, logging-while-drilling (LWD) tools and measuring-while-drilling (MWD) tools have found favor in the oil and gas industry.

[0005] During drilling, downhole devices, such as MWD and LWD devices, may communicate with the surface devices by way of telemetry systems. The medium for exchange of information between the downhole devices and the surface devices may be the drilling fluid (or mud) within the drill string, or the drill string itself. When using the drilling mud as the communication medium, the information may be imparted in the form of positive or negative pressure pulses. Alternatively, the information may be imparted into the drilling mud acoustically. Regardless of the method by which data communications takes place, telemetry

from downhole devices to surface devices is slow, on the order of one bit per second. For this reason, many downhole devices take measurements and read data, but store the data in internal memory for later retrieval.

[0006] Several types of downhole devices are used by the industry, and each device may require varying amounts of internal memory. For example, a “gamma” tool requires comparatively little memory; whereas, an acoustic or sonic tool may require a significant amount of memory, approaching 250 megabytes, to have the capability to store all the data gathered during a drilling run. Other downhole tools may comprise a resistivity tool, a caliper tool, and a directional tool.

[0007] For devices which store some or all of the gathered data in internal memory, once the tool is raised to the surface the data may be transferred to a surface computer. The most common way to transfer data from the internal memory of the downhole devices is to couple each downhole device to the surface computer by way of a cable. Once the cable is connected, the surface computer may communicate with the device, and transfer the data. While this operation seems relatively simple, several practical problems exist.

[0008] On most drilling rigs, especially drilling platforms on the ocean, space is a commodity, and therefore the surface computer may not, indeed most likely is not, close to the downhole devices even when they are on the rig floor. Thus, the cable used to transfer the information may be relatively long, and the data transfer rate decreases with length.

[0009] An additional factor that decreases the data transfer rate may be electrical noise. Drilling rigs have many motors and other electrical equipment associated with the drilling process, which equipment creates significant electrical noise. Because the download cable may wind in and around the drilling rig to get to the surface computer, it becomes an antenna for receiving electrical noise. Given the distance between a surface computer and the downhole devices, the length of the cable required and the ambient electrical noise, data transfer rates for communicating between the surface computer and the downhole device (while at the surface and coupled via the cable) may be at or near eighty kilo-baud. Transferring data from a memory-intensive logging device, *e.g.* an acoustic device, may take in excess of thirty minutes if no errors occur.

[0010] Various techniques exist to diminish the possibility that errors occur in the transfer of data, but these techniques are not infallible. On occasion, errors may precipitate a second transfer of the same information, and possibly even a third, until the information is transferred error-free. In instances where an error occurs and the transfer process repeated, significant rig time may be lost. The problem may be exacerbated still by the fact that bottomhole assemblies

may contain multiple logging devices, with each device having internal memory that needs to be transferred to the surface computer.

[0011] Thus, what is needed in the art is a more efficient mechanism to transfer data from the downhole devices to the surface computer.

SUMMARY OF SOME OF THE PREFERRED EMBODIMENTS

[0012] The problems noted above are solved in large part by a method and system of storing downhole data in a detachable memory device. One of the exemplary embodiments may be a method comprising coupling a memory device to a downhole device (while the downhole device is at the surface), lowering the downhole device into a borehole, operating the downhole device thereby creating data, storing the data to the memory device, raising the downhole device to the surface, disconnecting the memory device from the downhole device, coupling the memory device to a surface computer, and reading the data from the memory device by the surface computer.

[0013] Another of the exemplary embodiments may be a downhole tool comprising a downhole tool body having an outer surface, a processor disposed within the downhole tool body, and a connector disposed on the outer surface of the tool body (the connector couples a memory device to the processor). The memory device, when coupled to the connector, travels with the downhole tool body into and out of the borehole, and wherein the processor stores data to the memory device while the memory device and the downhole tool body are within the borehole.

[0014] The disclosed devices and methods comprise a combination of features and advantages which enable it to overcome the deficiencies of the prior art devices. The various characteristics described above, as well as other features, will be readily apparent to those skilled in the art upon reading the following detailed description, and by referring to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] For a detailed description of exemplary embodiments of the invention, reference will now be made to the accompanying drawings in which:

[0016] Figure 1 illustrates a drilling system constructed in accordance with embodiments of the invention;

[0017] Figure 2 illustrates an exemplary set of electronic components for a downhole device;

[0018] Figure 3 illustrates the non-volatile memory, after it is decoupled from the downhole device, coupled to the surface computer 246;

[0019] Figure 4 illustrates a flow diagram of a method in accordance with embodiments of the invention;

[0020] Figure 5 illustrates a partial cross-sectional view of one sidewall of a tool body in accordance with embodiments of the invention; and

[0021] Figure 6 illustrates an elevational cross-sectional view of a downhole device in accordance with alternative embodiments of the invention.

NOTATION AND NOMENCLATURE

[0022] Certain terms are used throughout the following description and claims to refer to particular system components. This document does not intend to distinguish between components that differ in name but not function.

[0023] In the following discussion and in the claims, the terms “including” and “comprising” are used in an open-ended fashion, and thus should be interpreted to mean “including, but not limited to...”. Also, the term “couple” or “couples” is intended to mean either an indirect or direct connection. Thus, if a first device couples to a second device, that connection may be through a direct connection, or through an indirect connection via other devices and connections.

[0024] The methods and systems described in this specification find applicability in many types of downhole devices. Downhole devices may launch or release energy into the formation, and then receive or detect the energy after it reacts with the formation to determine formation and/or borehole characteristics. Thus, the term “energy” as used herein means energy of any kind, such as electromagnetic waves, acoustic energy, radiation (*e.g.* gamma radiation), and/or high energy particles (*e.g.* neutrons). Moreover, the following description describes the gathering of data. Data may be not only information about a borehole and/or the formation surrounding a borehole; but may also comprise information about a downhole tool (*e.g.* voltages, currents, failure modes, error reports) that may assist in failure analysis.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0025] Figure 1 illustrates a drilling system 10 constructed in accordance with embodiments of the invention. The drilling system 10 may comprise a drill string 12 having a drill bit 14 disposed on the lower end of a bottomhole assembly 16. Rotation to the drill bit 14 may be accomplished by turning the drill string, as indicated by arrow 18, by surface equipment (not specifically shown). In alternative embodiments, a downhole mud motor 20 may couple to the drill bit 14, and may rotate the drill bit with power derived from drilling fluid flow within the drill string 12. In some embodiments, rotation of the drill bit 14 may be provided by a combination of the rotation of the drill string and the mud motor 20. Regardless of the precise

mechanism by which the drill bit is turned, the drill bit cuts through downhole formations to create a borehole 22.

[0026] In accordance with embodiments of the invention, the bottomhole assembly 16 may comprise various downhole devices, such as a logging-while-drilling (LWD) device 24 and a measuring-while-drilling (MWD) device 26. MWD and LWD devices may gather data about the borehole and the formations surrounding the borehole. Some of this information, most notably at least part of the MWD information, may be transmitted to the surface by way of a telemetry system, such as a mud pulse telemetry system. However, some data gathered downhole may not be needed at the surface immediately, and other data (*e.g.* data gathered by the LWD tool 24) may be too voluminous to transmit to the surface using pulse telemetry systems. For this reason, downhole devices such as the LWD tool 24 and MWD tool 26 may store some or all of the data gathered within the tool. Once at the surface, the data gathered may be transferred to a surface computer.

[0027] Figure 2 shows an exemplary set of electronic components for a downhole device. In particular, Figure 2 shows exemplary components for an electromagnetic wave resistivity tool. While the following discussion is thus directed to an exemplary downhole device being an electromagnetic wave resistivity tool, the discussion should not be construed as limiting the application of the embodiments of the invention to just electromagnetic wave resistivity tools. Any downhole device (*e.g.* acoustic tools, nuclear magnetic resonance tools, electromagnetic wave resistivity tools) which gathers data regarding the borehole and/or the surrounding formation may implement the techniques and systems described herein.

[0028] Figure 2 shows two source devices 202 and 204. Because the exemplary tool is an electromagnetic wave resistivity tool, each of the source devices 202, 204 may be an antenna that transmits energy in the form of electromagnetic waves. The exemplary downhole tool also comprises a plurality of receiving devices 206, 208. In the exemplary case of an electromagnetic wave resistivity tool, the receiving devices 206, 208 may be antennas tuned to receive energy in the form of electromagnetic waves. The interrogating energy sent forth from the source devices 202, 204 may originate with a processor 210 executing a program. The processor 210 may command a digital-to-analog (D/A) converter 212, as well as a D/A converter 214, to generate signals having the desired frequency. In the case of source device 202, the signal generated by the D/A converter 212 may couple to a bandpass filter (BPF) 216, which may filter out undesirable components of the signal. In alternative embodiments, the filter 216 may equivalently be a low pass filter or a high pass filter. The signal exiting the bandpass filter 216 may couple to a power amplifier 218, which increases the

signal strength of the exemplary signal, and couples it to the source device 202. Likewise, for the source device 204, D/A converter 214 may generate a signal which couples to the bandpass filter 220. The signal exiting the bandpass filter 220 may couple to an amplifier 222, which in turn couples the signal to the source device 204.

[0029] In the exemplary case of an electromagnetic wave resistivity tool, after one or both of the source devices 202, 204 operate, the receiving devices 206, 208 may receive energy in the form of electromagnetic waves indicative of borehole and/or formation characteristics. Beginning with the exemplary receiving device 206, the electromagnetic wave detected may be amplified by amplifier 224 and passed to a filter 226 to create a filtered signal. Although filter 226 is shown to be a bandpass filter, any filter which removes unwanted noise may be equivalently used. The filtered signal may then be coupled to an analog-to-digital (A/D) converter 228, which converts the analog signal to a digital representation which may be read by the processor 210. Likewise, with respect to receiving device 208, the electromagnetic wave detected may be coupled to an amplifier 230, and in turn coupled to a bandpass filter 232 and the A/D converter 228. The processor, by correlating the amplitude and phase of received signals to the source signals, may determine pertinent characteristics of the borehole and/or formation. In the case of an electromagnetic wave resistivity tool, the downhole device may be able to determine the resistivity of the surrounding formation, which may be indicative of the presence of hydrocarbons and/or boundaries between hydrocarbon-producing formations. If the exemplary downhole device is an acoustic device, the source devices 202, 204 would be acoustic transmitters, and their receiving devices 206, 208 would be acoustic receivers. Alternatively in the case of an acoustic device, the downhole device may be able to operate as a televiewer, showing characteristics of the borehole. In yet further alternative embodiments, one or more of the source devices 202, 204 may be (or control) a neutron source or gamma radiation source. In this case, the receiving devices 206, 208 may be gamma radiation detectors.

[0030] In accordance with embodiments of the invention, the processor 210 may execute a program which performs the desired control and calculations. The program may initially be stored on a read-only memory (ROM) 234. The processor 210 may likewise be coupled to a random access memory (RAM) 236. The RAM 236 may be the working area from which the processor 210 reads program steps and stores information. The processor 210 may likewise couple to a communication (COM) device 238, which may allow the processor to communicate with the surface computer through a cable coupled to the surface computer. While the various electronics for the exemplary downhole device may be separate components as illustrated in

Figure 2, in some embodiments the functionality of the D/A converters, A/D converters, RAM, ROM, processor and communications capability may be incorporated in a microcontroller, as indicated by dashed line 240.

[0031] In accordance with embodiments of the invention, in addition to, or in place of, the RAM 236, non-volatile memory 242 may couple to the processor 210. As indicated by the connection 244, the non-volatile memory 242 may be removably coupled to the processor 210. Preferably, as the downhole device gathers data regarding parameters of the borehole and/or formation, that data may be stored in the removably coupled non-volatile memory 242. Thus, the non-volatile memory 242 is coupled to the processor 210 while the downhole device is downhole and making the measurements. When the downhole device is raised to the surface, the non-volatile memory 242 may be disconnected from the downhole device, and coupled to the surface computer 246, as indicated in Figure 3. Thus, rather than transferring data to the surface computer by way of a cable coupled through the communication device 238, the data may be stored in a non-volatile memory 242 and the non-volatile memory transferred to the surface computer. Additional different non-volatile memory devices may then be attached to the downhole device's processor 210, and drilling continued without the delay associated with the exchange of data between the processor 210 and the surface computer 246. As illustrated in Figure 2, the non-volatile memory 242 may be one or a plurality of devices, depending on the amount of data gathered and stored by the downhole device.

[0032] The non-volatile memory 242 may take many forms. In accordance with at least some embodiments of the invention, the non-volatile memory 242 may be non-volatile random access memory (NVRAM). The NVRAM may take many forms, *e.g.* random accessory memory with a battery backup, a combination of SRAM and electrically erasable programmable read-only memory (EEPROM), or a solid state magnetic-type RAM. Alternatively, the non-volatile memory 242 may comprise one or more EEPROMs, which are periodically written with data generated by the downhole device. In still other embodiments of the invention, the non-volatile memory may be some form of optical storage media (*e.g.* CD-ROM or other optical device known in the art or after developed). Thus, any removably coupled persistent storage media may be used to store downhole data. The non-volatile memory 242 may be addressed serially, such as by a universal serial bus (USB), or may be some form of standards-based or proprietary package, such as a PCMCIA compliant device, a Smart Media device (originally developed by Toshiba), or a Compact Flash device (originally developed by Sandisk).

[0033] Figure 4 illustrates a flow diagram of a method in accordance with embodiments of the invention. In particular, the process may start (block 400) and move to coupling a non-volatile memory to the downhole device (block 402) while the downhole device is at the surface. After coupling of the non-volatile memory, the bottomhole assembly (BHA) comprising the downhole device may be lowered into the borehole (block 404). Thereafter, drilling may be commenced and the downhole device may store data regarding the downhole parameters in the non-volatile memory (block 406). Drilling may periodically cease and the bottomhole assembly may be raised to the surface (block 408). Once at the surface, the non-volatile memory may be detached or decoupled from the downhole device (block 410) and physically carried proximate to and coupled to the surface computer (block 412). Thus, the non-volatile memory is removably coupled from the downhole device. Thereafter, the surface computer may have access to and/or copy the data at the same access speeds as any other memory closely coupled to the surface computer (block 414). Thus, the process may end (block 416).

[0034] As discussed with respect to Figure 2, the non-volatile memory device 242 upon which data is stored, and thereafter coupled to the surface computer 242, need not be the only available device. That is, drilling rig operators and/or owners may have many of the non-volatile memory devices at their disposal, and thus a new non-volatile memory device 242 may be coupled to a downhole device and drilling continued, with the coupling of the non-volatile memory storing data to the surface computer taking place at any time.

[0035] Thus, embodiments of the invention envision a system in which non-volatile memory may be removed at the surface and replaced (either after reading or by a different device). Figure 5 illustrates a mechanism that may be used in accordance with at least some embodiments of the invention to both mechanically and electrically couple a non-volatile memory 242 to the processor 210. In particular, Figure 5 shows a partial cross-sectional view of one sidewall of a tool body 500 of the downhole device. Inasmuch as rotational forces from the surface may be transferred through the tool body to the drill bit 14 (Figure 1), the wall thickness may be relatively thick. At a desired location a Side Wall Read Out port (SWRO port) 502 may be included. The SWRO port 502 may thus comprise a recess within the tool body 500 that is internally threaded, such as by threads 504. A screw or cap may have an outside diameter slightly less than the internal diameter of the recess. The cap 506 may be externally threaded so as to mate with the internal threads 504. Because the SWRO port is preferably on an external surface of the tool body 500, it may occasionally come in contact with the borehole wall, and may also be exposed to drilling fluid. For these reasons, the cap 506

may seal to the tool body 500 by way of O-rings 508 and 510. The O-ring 508 may seal the threads against intrusion by foreign material, and the combination of O-ring 508 and 510 may seal the internal components of the cap 506 from foreign material, such as cuttings and drilling fluid.

[0036] In accordance with embodiments of the invention, the SWRO port may contain the non-volatile memory 242. The memory 242 may couple to a connector 512, which holds the non-volatile memory in place and electrically or optically couples the non-volatile memory to the processor 210. The cap 506 may also, in whole or in part, physically hold the non-volatile memory 242 in place.

[0037] Figure 6 shows an elevational cross-sectional view of a downhole device constructed in accordance with alternative embodiments of the invention. In particular, the downhole device may comprise a tool body 600. While the tool body is circular, in the cross-sectional elevational view of Figure 6 only the opposing side walls are shown. The upper end of the tool body may comprise a “box end” 602, and the opposite end may comprise a “pin end” 604. Thus, the downhole device may be coupled with a bottomhole assembly by connecting the box end 602 to the pin end of a drill string or other device above the downhole device in the drill string, and by coupling the pin end 604 to a mud motor or some other device below the downhole device in the drill string. The downhole device may likewise comprise a channel 606 fluidly coupling the box end 602 to the pin end 604. The channel 606 may be the fluid flow path for the drilling fluid within the drill string. The flow path of the drilling fluid may be coaxial with the tool body (not specifically shown), or as illustrated may be offset to allow more room for other components.

[0038] In accordance with embodiments of the invention, an electronics insert 608 may be placed on an inside diameter of the tool body 600. The electronics insert 608 preferably contains electronics illustrated in Figure 2. In these embodiments, insertion of the electronic insert is preferably through the box end 602 when the downhole device is not coupled within a bottomhole assembly. In the case of a downhole device being an MWD tool, the electronic insert may comprise devices for determining the orientation of the bottomhole assembly, and thus have few or no connections to components in operational relationship to an outer surface of the tool body. In embodiments where the downhole device is a LWD tool, the electronics insert 608 may couple to a source device, *e.g.* 610, and a receiving device, *e.g.* 612. In the exemplary case of an electromagnetic wave resistivity tool, the source device 610 may be a transmitting antenna, and the receiving device 612 may be a receiving antenna. In the

exemplary case of the downhole device being an acoustic tool, the source device 610 may be an acoustic transmitter, and the receiving device 612 may be an acoustic receiver.

[0039] Regardless of the precise nature of the downhole device, in accordance with embodiments of the invention, a non-volatile memory 242 may couple to the electronic sensor 608. The non-volatile memory 242 may be coupled to the electronic sensor 608 by insertion of the non-volatile memory through the box end 602, as indicated by arrow 614. Likewise, once the non-volatile memory stores data gathered and/or generated downhole, the non-volatile memory 242 may be disconnected and coupled to the surface computer. The disconnection in these alternative embodiments may involve disconnecting the downhole device from the bottomhole assembly to obtain access to the non-volatile memory through the box end 602 of the downhole tool body 600. In accordance with embodiments of the invention, the non-volatile memory 242 may couple to a connector 616 on an external surface of the electronics insert 608. The connector 616 may thus couple the non-volatile memory 242, external to the electronics insert, to the processor 210 within the electronics insert. While the connector is shown to be a part of the external housing of the electronics insert 608, there may be one or more intervening devices and systems between the connector 616 and the electronics insert 608. Further, depending on the nature of the non-volatile memory 242, a system such as that illustrated with respect to Figure 5, having a connector within a recess and protected by a cap, may be implemented in the embodiments of Figure 6 with access to the cap being through the box end 602 when the downhole tool body is disconnected from the bottomhole assembly.

[0040] The above discussion is meant to be illustrative of the principles and various embodiments of the present invention. Numerous variations and modifications will become apparent to those skilled in the art once the above disclosure is fully appreciated. It is intended that the following claims be interpreted to embrace all such variations and modifications.